Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 2, Pages 211-224, April-June 2024

Utilization of Green Synthesis for Eco-Friendly Nanomaterials and Their Advanced Biomedical Applications in Noble Metal Nanoparticles

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DOI: https://doi.org/10.38177/ajast.2024.8220

Article Received: 09 April 2024 Article Accepted: 17 June 2024 Article Published: 25 June 2024

ABSTRACT

Nanoparticles, the foundation of nano-science and nanotechnology, possess significant power and functionality across various fields. These nanoparticles are typically created through physical or chemical processes, but concerns surrounding toxicity have been raised. This discussion explores several environmentally friendly and low-toxicity green synthesis methods as alternatives. Many nanomaterials have been created and effectively applied in a variety of applications as nanotechnology has advanced. It is still difficult to create nanomaterials with appropriate functional characteristics, particularly for biomedical uses. Currently, a significant amount of the nanomaterials created for these uses are heavily dependent on non-renewable resources and energy-intensive manufacturing techniques. Furthermore, the long-term impacts of these unsustainable nanomaterials on human health, the environment, and climate change lag behind the exponential development in their innovation and discovery. A sustainable nanomaterial design that uses natural and renewable resources and has the least negative effects on society is therefore desperately needed. Green synthesis, which employs plant extracts rather than synthetic chemical agents to lower metal ions, was created as a solution to these problems. Because green synthesis is less expensive, produces less pollution, and enhances the safety of the environment and human health, it is preferable to traditional chemical synthesis. This review assessed recent advancements in the environmentally friendly synthesis of silver (Ag NPs) and gold (Au NPs) nanoparticles. Green synthesis, on the other hand, offers different development opportunities and possible applications in light of the present environmental issues and pollution linked to chemical synthesis.

Keywords: Nanotechnology; Green synthesis; Sustainability; Renewable resources; Nanoparticles; Biomedical applications; Microbiological synthesis; Enzyme synthesis; Silver nanoparticles; Gold nanoparticles; Drawbacks of green synthesis.

1. Introduction

Nanotechnology is a young scientific field that examines materials or particles with sizes between 1 and 100 nm (1 nm ¼ 10). At the 1974 international conference on industrial production in Tokyo, N. Taniguchi coined the word "nanotechnology" to refer to the extremely thin development of materials inside the nanoscale range [1]. The advancement of scientific and technological fields has been greatly aided over the years by nanotechnology and nanomaterials. In particular, there has been a lot of interest in nanomaterials, including metal, polymer nanoparticles, graphene, and nanotubes. Because of their size, these nanomaterials display exceptional physio-chemical characteristics, including greater reactivity, molar extinction coefficients, absorption and surface area, tunable plasmonic capabilities, photo and magnetic properties, and quantum effects [2]. Small molecule therapeutics have received a lot of attention, especially in the field of biomedical applications to human health, despite their serious drawbacks, which include poor photo stabilities, non-biocompatibility, adverse effects on other organs, rapid renal clearance, a shorter retention time in blood fluids, poor targeting ability, and insufficient cellular uptake [2].

1.1. Study Objectives

(i) Terminology and Historical Development: To investigate the early phases of the development of nanotechnology and its first uses in several scientific domains.

(ii) The description of nanomaterials: To investigate the distinct physio-chemical properties of nanomaterials, such as their surface area, plasmonic potential, reactivity, molar extinction coefficients, absorption qualities, photo

and magnetic properties, and quantum effects. To examine the behaviour and structural characteristics of several nanomaterials at the nanoscale (1-100 nm), including metal, graphene, polymer nanoparticles, and nanotubes.

(iii) Technological Progress in Nanotechnology: To evaluate the ways in which nanotechnology has advanced scientific and technological domains over time. To compile a list of significant discoveries and advancements in nanomaterials that has advanced numerous sectors.

(iv) Applications in Biomedicine: To research the use of nanomaterials in biomedicine, with an emphasis on how they can improve the effectiveness of small-molecule treatments. To assess how well nanomaterials work in biomedical applications, such as better blood fluid retention, cellular uptake, and targeting capabilities.

(v) Obstacles and Restrictions: To list and evaluate the main disadvantages of employing nanomaterials in biomedical applications, including fast renal clearance, non-biocompatibility, poor photo stabilities, and negative effects on other organs. To make suggestions for possible approaches and remedies to these problems in order to improve the security and efficacy of nanomaterials in medical applications.

(vi) Research and Future Paths: To describe potential avenues for nanotechnology research in the future, with an emphasis on resolving current issues and investigating novel uses. To make creative suggestions for the scalable and sustainable manufacturing of nanomaterials with enhanced qualities for a range of uses.

2. Eco-friendly nanomaterials for use in biomedicine

For the creation of nanoscale materials, nanotechnology has shown to be a game-changing technology. Nanomaterials have a huge surface area to volume and unique size, shape, and composition-dependent features that make them appropriate for a wide range of practical applications, including the environment, biomedicine, and renewable energy [3]. Wireless bandages that promote wound healing for people living in both urban and rural areas, wearable medical devices/sensors, and the discovery of mRNA vaccines for COVID-19 using lipid nanoparticles have all been made possible by the scientific revolution in nanotechnology [4-6].

People are turning to herbal-based antimicrobial treatments, which are efficient, environmentally friendly, and comparatively devoid of side effects, in order to avoid such severe and potentially fatal adverse effects. In order to find this, we searched with the following keywords: "green AND synthesis AND nanoparticles AND plant." Researchers have experimented with many techniques, such as physical and chemical procedures, to synthesize nanoparticles. These techniques, however, were costly, time-consuming, and required complex electrical or electronic equipment. These techniques involve harmful chemicals that pose several health risks and are not environmentally friendly [7].

Nanotechnology has enormous potential for creating the upcoming generation of sensors and medical devices [8,9], diagnostics, nanovaccines, and implants [10-13], and technology for therapy [14,15]. Over the past twenty years, a great deal of research has been done to create manufacturing processes for creating functional nanomaterials that involve both top-down (chemical reduction and sol-gel) and bottom-up (lithography and etching). As a by-product of these production processes, hazardous waste is produced, endangering both the environment and workers right away. In addition, improper synthesis and handling of nanomaterials can have detrimental short- and long-term

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effects on the environment and public health [16]. Furthermore, the development of nanomaterials-based medicine for clinical applications has been primarily hampered by concerns about the safe manufacture, safe handling, and lack of clinical evidence. Therefore, while creating safe nanomaterials for biomedical applications, consideration should be given to the selection of raw materials (precursor materials), manufacturing process (cost and scalability), and handling guidelines.

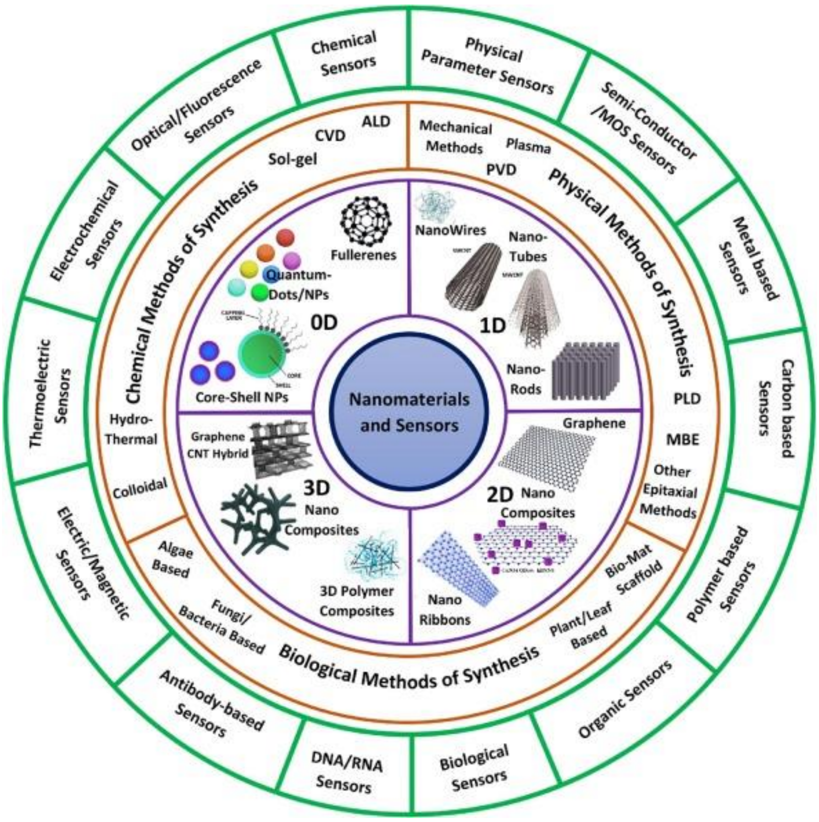

Figure 1. The creation of sustainable nanomaterials and their use in biomedicine for a sustainable future [17]

In order to minimize the negative effects of nanoparticles on society and the environment, sustainable nanotechnology involves the safe manufacture of sustainable nanomaterials throughout the design stage of product development to establish environmentally friendly production techniques.

3. Green Synthesis

Biological organisms or plant extracts are used as reducing and stabilizing agents in the environmentally friendly process known as "green synthesis" of nanoparticles. Green synthesis has more advantages than traditional chemical synthesis since it is less expensive, produces less pollution, and enhances the safety of the environment and human health [18].

4. Green methods for synthesizing nanoparticles

Green synthesis offers numerous benefits in comparison to traditional chemical and physical methods. Not only is it non-toxic, but it also contributes to a pollution-free environment [19], Eco-friendly and cost-effective [20], and enhancing Sustainability. However, there are problems with raw material extraction, reaction times, and final

product quality [21] Figures 2 and 3 illustrate various green synthesis techniques for nanoparticles. By using less energy and dangerous materials, these techniques provide a sustainable substitute for traditional chemical and physical processes. The above references will be useful for additional in-depth information.

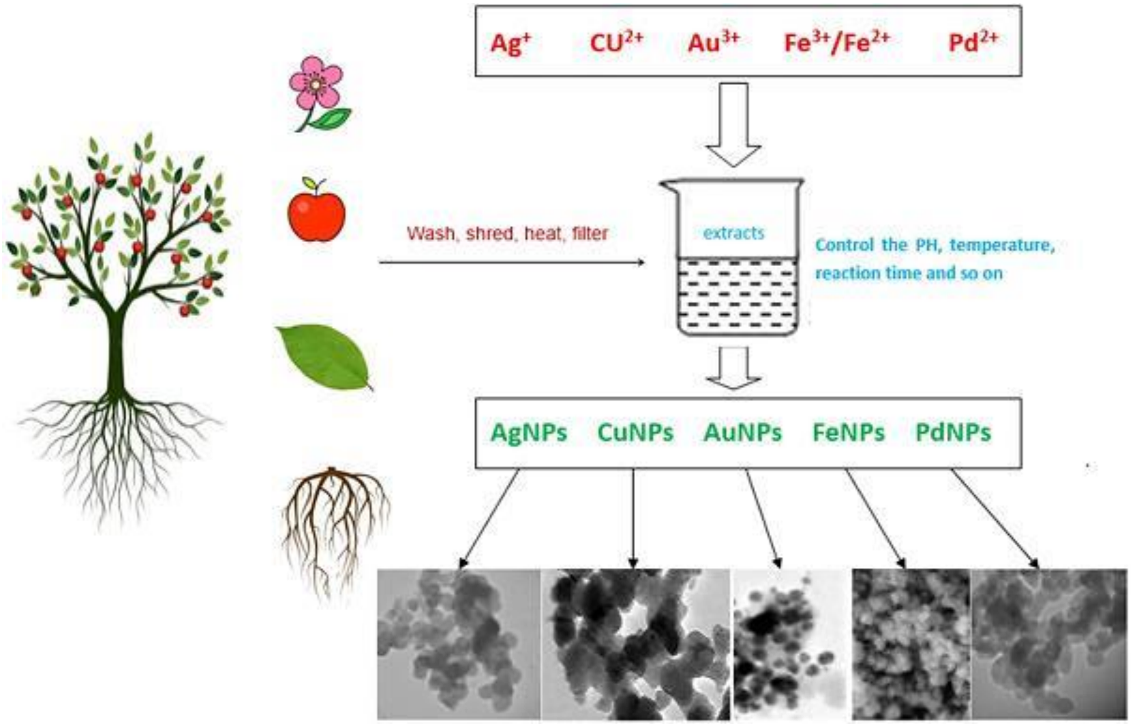

Figure 2. Types of Green Synthesis of Nanoparticles [18]

(i) Synthesis Mediated by Plant Extract

Takes metal ions from plants (leaves, roots, fruits, etc.) and uses them to make nanoparticles. The plant extracts' phytochemicals function as capping and reducing agents.

Example: Silver nanoparticle synthesis employing leaf extract from *Azadirachta indica* (neem) [22].

(ii) Microbiological Synthesis

Uses microorganisms to biosynthesize nanoparticles, including fungi, bacteria, and algae. The stability and reduction of nanoparticles are greatly aided by the action of microbial metabolites and enzymes.

Example: *Fusarium oxysporum* was used to create gold nanoparticles [23].

(iii) Synthesis Mediated by Enzymes

Involves catalyzing the creation of nanoparticles using enzymes extracted from biological systems. High selectivity and control over the creation of nanoparticles are possible with enzymes.

Example: Gold nanoparticle synthesis with the α-amylase enzyme [24].

(iv) Synthesis Mediated by Polysaccharides

Uses cellulose, chitosan, or starch—all naturally-occurring polysaccharides—as reducing and capping agents throughout the nanoparticle manufacturing process.

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Example: Chitosan was used to manufacture silver nanoparticles [25].

(v) Synthesis Mediated by Biomolecules

Involves stabilizing nanoparticles and reducing metal ions by use of biomolecules such proteins, amino acids, and vitamins.

Example: Gold nanoparticle synthesis with vitamin C (ascorbic acid) [26].

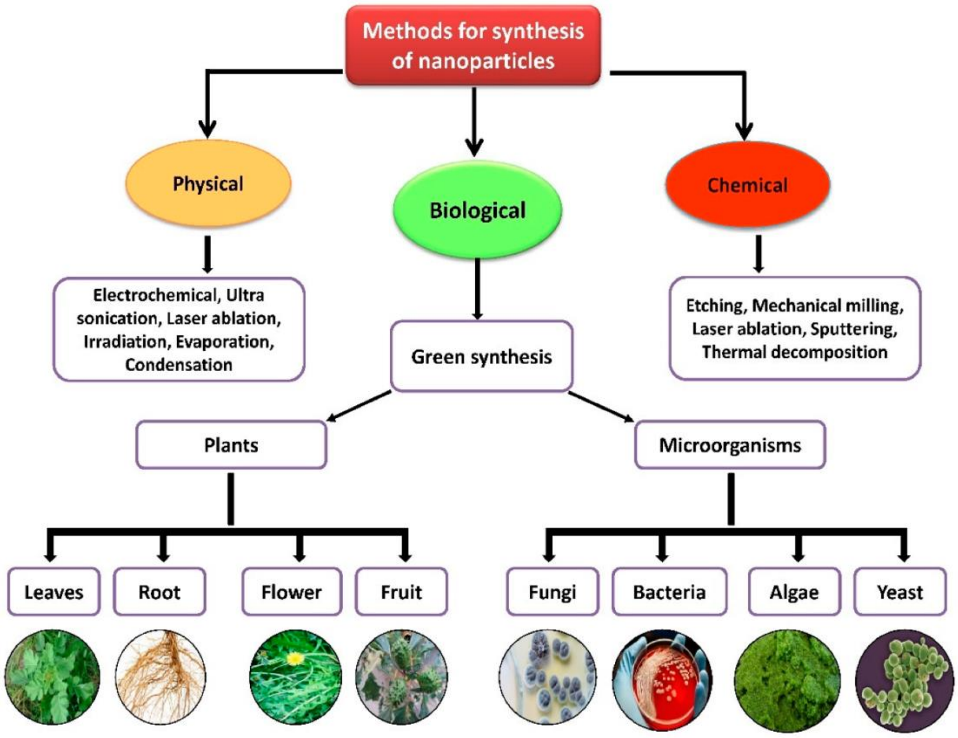

Figure 3. Different techniques for creating nanoparticles [27]

Table 1. Benefits and drawbacks of chemical, physical, and green synthesis [28-45]

S. No.	**Methods**	**Benefits**	**Drawbacks**
	Physical Procedures		
1.	Laser Ablation	Make uncontaminated, pure nanoparticles free of chemicals. Able to modify settings to regulate form and size.	High usage of energy. Costly machinery and upkeep expenses.
2.	Ball milling	Easy and economical to use. Ideal for industrial manufacture.	Wide range of sizes and possible contamination. Restricted ability to adjust particle size.

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3.	Thermodynamic Disintegration	Generates superior-grade nanoparticles. Permit effective management of particle size.	Potential generation of secondary products.
	Chemical Procedures		
1.	Reduction of chemicals	Able to generate a lot of nanoparticles. Good management of form and size.	Utilizing hazardous substances and solvents. Possible risks to the environment and health.
2.	Sol-gel method	Generate extremely homogenous nanoparticles. Permit the integration of nanoparticles into different types of matrices.	Laborious procedure. Need exact control over the state of the reaction.
3.	Micro emulsions	Generate single-disperse nanoparticles. Easy and adaptable techniques.	Challenging to scale up.
	Green Synthesis Procedure		
1.	Plant-Based Extracts	Sustainable and beneficial to the environment. Accessible and reasonably priced row materials. No requirement for harmful substances.	Variability in the content of plant extracts. Restricted scalability.
2.	Microbiological Synthesis	Both environmentally benign and biocompatible. Possibility of extensive output. Utilization of renewable natural	Longer times during synthesis. Need certain growing circumstances. Hazardous potential contamination.

		energy sources.	
3.	Enzyme-Induced	High control over synthesis and specificity. Gentle response state.	Costly and might need enzyme purification. Problems with enzyme activity and stability.
4.	Mediated by polysaccharides	Non-toxic and biodegradable. Makes use of renewable resources.	Restricted ability to manipulate particle form and size. Potential breakdown of polysaccharides.
5.	Bio-Molecular-Induced	Both non-toxic and biocompatible. Able to create nanoparticles with functionality.	Possibility of biomolecule activity fluctuation. Increased expenses and restricted scalability.

This table highlights the various advantages associated with each methods providing a clear overview of their respective benefits and challenges.

5. Applications of green-synthesized noble metal nanoparticles in biomedical

The usefulness and significance of Nobel metals (NMs) are widely acknowledged, while their toxicity remains unclear in many disciplines. Daily production of nanoparticles is rising from multitone black to microgram levels, with ferocious silica and other materials being produced primarily for biological purposes [46].

1. Antimicrobial Substances

Application: Strong antibacterial effects of green produced nanoparticles, especially gold and silver, are demonstrated against a wide range of pathogens, including bacteria, viruses, and fungus. Example: It has been demonstrated that plant extracts, such as neem and tea, can be used to create silver nanoparticles that efficiently stop the growth of different bacterial strains [50,51].

2. Systems for Delivering Drugs

Application: To increase a drug's effectiveness and lessen its adverse effects, noble metal nanoparticles are utilized to deliver the medication straight to the tissues or cells that need it. Example: To deliver anticancer medications straight to tumor cells, plant-derived chemicals are functionalized into gold nanoparticles [52].

3. Diagnostic and Bioimaging Instruments

Application: Noble metal nanoparticles are employed in a variety of imaging methods, including optical coherence tomography, fluorescence imaging, and X-ray imaging, because of their special optical characteristics. Example: Greenly produced gold nanoparticles improve contrast in imaging tools to help in early disease diagnosis [53].

4. Cancer Treatment

Application: In photo thermal therapy, noble metal nanoparticles are used to kill cancer cells by converting light into heat. Example: Biologically produced gold nanoparticles have been utilized to selectively target and eradicate cancer cells using photo thermal ablation [54].

5. Healing of Wounds

Application: Silver nanoparticles' antibacterial qualities hasten the healing of wounds by averting infections. Example: Wound dressings are enhanced with plant extract-derived silver nanoparticles for quicker healing [55].

6. Biosensors

Application: Noble metal nanoparticles have a high sensitivity and specificity, which makes them useful in biosensors that detect infections and biomolecules. Example: Greenly produced gold nanoparticles are used in biosensors to measure diabetes patients' blood glucose levels [56].

These uses demonstrate the adaptability and promise of environmentally friendly, synthetic noble metal nanoparticles in a range of biological domains. These applications are safe for human health and the environment, thanks to the environmentally favorable synthesis pathways.

6. Conclusion

In order to address social issues in the areas of energy, the environment, the economy, and biomedicine, the idea of sustainability was developed. Sustainable nanoparticles produced with little production of hazardous waste and utilizing scalable, environmentally friendly production processes with renewable resources. One viable approach to creating sustainable nanomaterials using recycled garbage as a renewable resource is the implementation of a zero-waste manufacturing process. Because of its potential applications, green production of nanoparticles is a topic of interest for scientists worldwide. It is possible to synthesize nanoscale metals sustainably. A significant amount of research on the green synthesis of nanoscale metals has been published in recent years.

However, there are a number of obstacles and drawbacks to green synthesis, including low yield, irregular particle sizes, intricate extraction processes, seasonal and regional raw material availability, and other issues that must be resolved for the production and use of green synthesized nanomaterials in practical applications. Thus, future research must focus on increasing the production of nanoscale metal particles, utilizing inexpensive raw materials, and implementing straightforward energy-saving technologies.

7. Future Suggestions

To address variations in yields and particle sizes, standardize the procedures for the environmentally friendly synthesis of nanoparticles. This would facilitate the manufacture of nanoparticles with consistency and reproducibility.

To improve the viability and sustainability of the synthesis of green nanoparticles. Examine a wider variety of affordable and easily accessible raw materials, such as industrial byproducts, agricultural trash, and other recycled waste types.

Make an effort to streamline and enhance green synthesis methods in order to increase their scalability and energy efficiency. Costs and energy consumption could be greatly decreased by conducting research on innovative catalysts and ideal reaction conditions.

Encourage the incorporation of the production of green nanoparticles into a circular economy. This includes creating closed-loop systems that maximize resource usage by using trash from one process as an input for the creation of nanoparticles, thus reducing waste.

Undertake thorough investigations to tackle the difficulties associated with transferring green synthesis procedures from laboratory to industrial settings. To test and improve large-scale production techniques, this involves working with industry partners on pilot projects.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors took part in literature review, analysis and manuscript writing equally.

Availability of data and material

All data pertaining to the research is kept in good custody by the authors.

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